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ABSTRACT

The American Chemical Society (ACS) sponsored a workshop for 32 invited participants to consider chemistry instruction in the kindergarten-through-ninth-grade curricula. This document represents the final report of the conference to the ACS Committee on Chemical Education. An introduction presents an overview of the conference and perspectives on K-9 science education. Specific recommendations follow, and are categorized as: (1) implementation strategies; (2) the K-9 science curriculum; (3) in-service teacher education; (4) preservice teacher education; and (5) general conclusions. The texts of the plenary addresses delivered to the participants are also provided. These include "The Status and the Problems of K-9 Science" (Robert E. Yager); "What to Do about Science in the Elementary School" (Mary Budd Rowe); and "Thoughts on Designing a K-9 Chemistry Curriculum" (J. Arthur Campbell). The document also contains a bibliography and a list of the speakers and participants. (TW)

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Report with Recommendations

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Final Report of the 1982 Invitational Education Workshop
Sponsored by the Society Committee on Chemical Education
of the American Chemical Society

Reston, Virginia
December 3–5, 1982

Chemistry in the Kindergarten-through-Ninth-Grade Curricula: Report with Recommendations

Workshop Chairman
Henry Heikkinen, *University of Maryland*

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Introduction

An Overview

The American Chemical Society Committee on Chemical Education periodically calls together a relatively small group of national leaders in science education to discuss contemporary issues and define future goals. These sessions have played an important role in developing Society policy and in defining chemical education programs.

A three-day workshop was convened for 32 invited participants in Reston, Va., on Dec. 3, 1982, to consider chemistry instruction in the kindergarten-through-ninth-grade curricula. The workshop participants considered four questions related to the major theme of the role of chemistry in the K–9 curricula: What should be taught? Who should teach it? How should recommendations be implemented? What should the roles of ACS (and related organizations) be in these matters?

The workshop focused on this difficult issue in recognition of the vital role elementary science instruction should play in fostering scientific literacy and in stimulating interest in science-related career goals. The acknowledged problems currently associated with elementary science teaching in the United States, documented by references listed in the workshop bibliography and clearly outlined by the workshop's three plenary speakers, suggest the urgency of constructive action by organizations and individuals concerned with the future of science and science education in the United States Transcripts of addresses by the three plenary speakers are included in this report.

In a fundamental sense, the entire K–12 (or perhaps even K–14) continuum should be considered in terms of appropriate science teaching. The focus on the pre-high school years in this workshop was intentional, however, to assure adequate attention to the special problems associated with teaching at these levels. In fact, even within the kindergarten-to-ninth-grade range, two rather different instructional settings appear, making generalizations and analyses more difficult. At the lower grades, teachers assume general responsibility for instruction in all academic areas (with the possible exception of areas such as art, physical education, and music). At the middle and junior high school levels, teachers become specialists in limited portions of the curriculum. Thus, differences in the needs and responsibilities of the "generalist" elementary teacher who supports many subjects in addition to science, and the "specialist" science teacher in the higher grades must be recognized.

Because of the complex nature of the workshop topic, an experienced and diverse group of individuals associated with science education was invited (see participant list). Classroom teachers, school administrators, science supervisors, curriculum developers, college professors from science departments and schools of education, and representatives from government and associated professional organizations helped to define and shape the final workshop draft recommendations.

It was agreed that the amount and quality of K–9 science presently taught in the schools is insufficient for a technological society, and is equally insufficient to meet basic academic goals. While available curricular materials generally address a goal of academic preparation, they often are inadequate to address other central goals. (See discussion of goal clusters.) It has been noted that much science that *is* taught in elementary grades tends to focus on life science and nature study. Relatively little attention is given to chemical or physical science at lower grade levels.

Despite the multi-faceted nature of problems facing K–9 science instruction, workshop participants felt that solutions are definable and implementable, given suitable efforts by groups associated with science instruction (including ACS). Participants left the workshop with the problem more clearly defined, and, as revealed in the workshop recommendations, with concrete ideas of how K–9 science instruction can be assisted and improved.

Recommendations presented in this report are intended to stimulate thought and action on these matters within ACS and within the entire science education community. Action is needed among many groups for significant progress to occur. The recommendations imply not only joint action at a national level among related professional organizations, but also locally based cooperative action and dialogue among (for

example) chemistry, biology, and physics departments and the department of education on a specific college or university campus. Suggestions regarding the specific nature of these local, regional, and national actions follow later in this report.

A View of K–9 Science Education

Workshop participants accepted four major goal clusters[1] as a framework for analyzing K–9 science education. These goal clusters emerged originally from Project Synthesis, directed by Norris Harms of the University of Colorado. The project synthesized and interpreted information reported earlier in three major National Science Foundation (NSF) studies of the status of U.S. precollege science and in reports from the National Assessment of Educational Progress (NAEP). The four broad goal clusters are:

- *Personal needs.* Science education should prepare individuals to utilize science for improving their own lives and for coping with an increasingly technological world.
- *Societal issues.* Science education should produce informed citizens prepared to deal responsibly with science-related societal issues.
- *Academic preparation.* Science education should allow students who are likely to pursue science academically as well as professionally to acquire the knowledge of science necessary for their needs.
- *Career education/awareness.* Science education should develop in all students an awareness of the nature and scope of the wide variety of careers related to science and technology that are open to students of varying aptitudes and interests.

The workshop's general views on K–9 science education, in light of the major goals identified for such instruction, can be described as follows:

Science should be a basic and continuous component of the elementary school program, integrating and reinforcing other curricular areas to make learning more meaningful for children than it would be if science were not a part of the curriculum. More emphasis should be placed on relevant mathematical skills in teaching elementary science than is now the case in many—perhaps even most—schools. In addition, integration of science teaching with reading, writing, and mathematics instruction should be actively promoted.

The elementary science curriculum should provide daily opportunities for continuous student exposure to science facts and concepts along with inquiry skill development and the use of scientific methods. Children should be encouraged to investigate their world by using an activity-oriented approach with a variety of resources—both print and nonprint—including audiovisual aids, and laboratory materials.

The elementary science program should foster in students an understanding, interest, and appreciation of their world. The science curriculum should address all four major goal clusters defined earlier, recognizing the special needs of students at this level.

The regular classroom teacher should teach science in the elementary grades. Such a teacher should have adequate background in science and should be provided adequate time for preparation of science activities. If this arrangement is not feasible, one alternative would be to use a science specialist to assist the regular teacher. Another alternative would involve having teachers who are well-prepared in science assume leadership in planning science experiences.

At all grade levels, integrating laboratory experimentation with the use of new technology (computers and videodisks, for example) should be explored. However, computer simulation should *not* be considered a substitute for direct student experience with scientific phenomena.

The middle or junior high school science curriculum should provide continuous opportunities to explore science through reading, discussion, laboratory, and field activities. While preparation for high school biology should be among the instructional goals at this level, systematic exposure to basic concepts in the physical sciences (especially chemistry and physics) coupled with work toward development of problem-solving skills also is important. Science should emphasize the relationship of both skills and content to students' personal experiences, and enable students to examine social issues involving science and technology.

[1]Adapted from Kahl, S. and Harms, N. "Project Synthesis: Purpose, Organization and Procedure." In *What Research Says to the Science Teacher, Volume 3*, edited by N. C. Harms and R. E. Yager, Washington, D.C.: National Science Teachers Association, 1981, p. 7–8.

Recommendations

I. Implementation Strategies

We recommend

a) that a special "Implementation Task Force" be appointed by the ACS Society Committee on Chemical Education and be charged with identifying segments of the Society, as well as other organizations and individuals, who will work toward implementation of the following recommendations. We further recommend that this Implementation Subcommittee monitor progress in the attainment of these recommendations and report semiannually to the parent Committee.

b) that ACS establish an office to deal with elementary science education that will disseminate science information to elementary teachers and communicate with other individuals and organizations concerned with K–9 science education (and also assist in the implementation activities defined in this report).

II. The K–9 Science Curriculum

We recommend

a) that a committee composed of chemists, science educators, elementary administrators, and teachers identify chemical topics and related societal issues appropriate for K–9 study. Criteria should be developed for selection and evaluation of appropriate materials.

b) that ACS selectively collect, disseminate, and if necessary generate resource and curricular materials featuring activities that can be used to teach chemistry-related topics in grades K–9. Emphasis should be on operationally complete and immediately useful classroom materials.

c) that a committee survey national and local K–9 testing programs in science in light of the goal clusters and views presented in this document and consider development of illustrative test items in physical science that address the full range of desired instructional outcomes. This recommendation is made in light of the observation that tests have a profound influence on curriculum and instruction.

d) that ACS work with other professional societies to promote integration of K–9 science with the teaching of reading, writing, and mathematics.

III. In-service Teacher Education

We recommend

a) that a committee develop continuous science in-service programs for K–9 teachers that are:

- locally based,
- directly related to K–9 science instruction,
- designed through collaboration of teachers, administrators, chemists, and science educators,
- maintained by local resource persons, and
- regularly evaluated for effectiveness.

b) that ACS provide guidance to chemists on how to contact and interact with associations of elementary and junior high school principals, science supervisors, and school boards to discuss current views on science teaching.

c) that ACS explore summer employment, travel grants, tuition scholarships, and other creative mechanisms to provide science-related experiences for K–9 science teachers to augment their science background and salaries.

d) that ACS encourage college and university chemistry departments to act jointly with schools of education to develop special programs for elementary teachers that merge suitable science content with effective teaching methods.

e) that, to communicate the excitement of science, a committee develop mechanisms whereby college and university departments of biology, chemistry, and physics can encourage appropriate faculty members to serve as active resource personnel for nearby K–9 science classes and on-campus education departments.

f) that ACS explore establishing regional and national electronic or computerized networks (for example, cable TV and teleconferences) to generate and distribute in-service, preservice, and continuing education programs and materials. Universities and colleges with such facilities could provide sites and personnel.

IV. Preservice Teacher Education

We recommend

a) that the American Association for the Advancement of Science (AAAS) re-examine its *Guidelines for Pre-service Elementary Teachers* (1970) and the National Science Teachers Association (NSTA) do likewise for its *Recommended Standards for the Preparation and Certification of Teachers of Science at the Elementary and Middle/Junior High School Levels* (1982) to determine implications for preservice teacher preparation. Special consideration should be given to preservice needs of middle school science teachers who assume more specialized responsibilities for science instruction.

b) that ACS work with other professional societies to sponsor symposia and workshops for improving college professors' teaching strategies, so they in turn can provide increasingly effective and appropriate instruction to preservice teachers.

V. General Considerations

We recommend

a) that ACS local sections

- develop "locator lists" of retired chemists available as resource persons to assist elementary and secondary school science teachers,
- augment science reference resources of schools and public libraries,
- initiate awareness programs to alert the professional chemical community to the current status of school science at the local level,
- encourage members to be active in local PTAs and school boards to improve science instruction in their schools, and
- expand their awards program to include recognition of elementary teachers who excel in science instruction.

b) that ACS encourage partnership programs between the chemical industry and local schools to improve science programs. Field trips and classroom visits by scientists are found in some schools now; other creative mechanisms also should be explored and encouraged.

c) that ACS investigate ways to promote out-of-school activities by elementary school students such as television and radio programs, home science kits, scouting merit badges, science magazines, science clubs, science fairs, and support of science museums and institutionally based (i.e., college and university) science-oriented programs for children.

d) that ACS explore establishing a toll-free telephone service through which K–9 teachers could pose questions related to chemistry teaching. Response and follow-up could be made through an ACS local section community liaison.

e) that ACS establish liaisons with other professional, scientific, and educational societies concerned with K–9 science.

f) that copies of the full workshop report be distributed by ACS to all professional organizations, agencies, and groups interested in K–9 science education. Permission to reprint the report should be granted to professional journals.

g) that periodic reports on progress in the above areas be published in appropriate journals and magazines such as the *Journal of Chemical Education, Chemical & Engineering News,* and suitable publications of other professional societies.

The Status and the Problems of K–9 Science

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Reports released during the past two years have established a new direction for school science. Many have compared the efforts of the past few years to those that occurred 25 years ago following the launching of the Soviet Sputnik in 1957. Such comparisons cause a certain hesitation today—perhaps because there was little caution, too few voices with fundamental questions, little doubt that the public demands and the corresponding response from the scientific community did not have "the" answers.

Two years ago, Philip Handler, then president of the National Academy of Sciences, spoke of the "lost confidence in the ultimate value of the scientific endeavor" by the general public. He talked of an antiscientific—and antirationalistic trend—that is ever present in our society of the 1980s, i.e., the news media, political debates, schools, and business. Such views are quite unlike the special place science was given a quarter of a century earlier.

In many respects, the programs of the 1960s met the specified goals. There was renewed interest in science—for a time we did seem to have students better prepared for college—even though not large numbers were clamoring for more science study. We did increase the number of scientists and engineers—sometimes to the point that persons with doctoral degrees could not find employment. We did "catch the Russians" in the space race with several spectacular achievements.

However, the early 1970s brought much disillusionment and questioning to society in general. The Vietnam tragedy was divisive; to many, science and technology were major culprits. The schools became suspect; test scores declined dramatically. (Some report that the declines were more a result of a loss of faith in the schools by the public, than of what actually was occurring in schools!) Many administrators, community leaders, and teachers were ready to blame these problems on the so-called new programs and teaching approaches developed during the sixties. But is such blame deserved?

There have been failures in school science. To be sure, these need attention. But they are not the problems that have stimulated the major discussion since 1976—the year that most new curriculum developments at the national level were all but terminated and the year that the National Science Foundation (NSF) curtailed all support for teacher in-service education.

Following these challenges in 1976, the NSF funded three huge status studies to assess the failures and successes of the grand national experiment in science education from 1956 to 1976. The major findings from these extensive studies of the past five years provide evidence that the general public is essentially illiterate in a scientific and technological sense even with the national efforts of the preceding 20 years. This illiteracy finds increasing expression in games, tarot cards, astrology, faddist approaches to nutrition, blind acceptance of advertising gimmicks, bandwagon approaches to solving energy and environmental problems, and erroneous views of the meaning of science and the ways scientists operate.

Some studies suggest that 90 percent of the current U.S. public is functionally illiterate with respect to science and technology. Literacy in science includes three features: expression of interest in an area (science); command of knowledge in an area; and ability to act based on knowledge, including a disposition to deepen interest and knowledge. Unfortunately, school science does little to enhance such literacy. In fact, the National Assessment of Educational Progress data suggest that interest in science decreases the longer a student stays in school. Other studies indicate that secondary science is ineffective in *increasing* knowledge across a four- or six-year program.

Although interest and knowledge are vital to literacy, the most important feature is the ability to use both, that is, the ability to act responsibly. Perhaps interest in science can be demonstrated on some level to exist in 30 percent of the high school graduates. Other studies reveal that as few as 25 percent of the graduates have a working understanding of basic concepts introduced in Grade 9. However, when interest and knowledge are combined with ability to take

action—ability to *use* such interest and knowledge—the figure drops to about 10 percent of high school graduates. There is some indication that the figure is even lower for the general public.

One example of the problem is the recent action of a judge in overturning a jury verdict. His reason was the inability of the jury to use scientific evidence introduced in the case. This is surely an example of the failure of our educational system to prepare citizens for living in today's society. In a democratic society we must have a citizenry able to make decisions—that is the essence of a democracy. And yet there is evidence in abundance that we do not have a citizenry capable of making the most basic decisions about our futures, our very being. This surely is a failing of our science programs.

Toward a New Focus

Recently, the National Science Teachers Association (NSTA) released a third volume of *What Research Says to the Science Teacher.* The volume was a report on Project Synthesis, a major NSF research effort designed to use the several huge data bases that the three status studies and the third assessment of educational progress provided. The so-called discrepancy model was employed by the synthesis researchers. This model includes a formulation of a "desired state condition," a review of the "actual state conditions," and a formulation of discrepancies between the two.

Project Synthesis provides a description of the "desired state condition" in elementary science, biology, physical science, inquiry, and science/technology/society. These conditions were derived from a careful study of various disciplines for new advances, reports of futurist groups, reviews of social indicators, a study of problems identified for solution by various foundations, a study of reports of school critics, and a review of the arguments of advocates for certain new advances and approaches.

One important contribution that Project Synthesis has provided is a clearer understanding of the goals for school science. Prior to funding the synthesis, researchers arrived at four goal clusters that provided a rationale for studying science in schools. These are:

- *Personal needs.* Science education should prepare individuals to utilize science for improving their own lives and for coping with an increasingly technological world.
- *Societal issues.* Science education should produce informed citizens prepared to deal responsibly with science-related societal issues.
- *Academic preparation.* Science education should allow students who are likely to pursue science academically as well as professionally to acquire the knowledge of science necessary for their needs.
- *Career education/awareness.* Science education should develop in all students an awareness of the nature and scope of the wide variety of careers related to science and technology that are open to students of varying aptitudes and interests.

Unfortunately, current science programs and most science teachers are concerned only with the third goal cluster. Well over 90 percent of the teacher effort, course structure, and measured outcomes are related to academic preparation goals. There is little or no attention paid to the other areas—those more likely to help in the production of a scientifically literate citizenry.

A composite scenario that represents the great majority of classrooms in elementary schools summarizes the findings of the Synthesis team concerned with the "actual state conditions" for science in U.S. elementary schools. The typical elementary science experience of most students is at best very limited. Most often, science is taught at the end of the day, if there is time, by a teacher who has little interest, experience, or training to teach science. Although some limited equipment is available, it usually remains unused. The lesson will probably come from a textbook selected by a committee of teachers or from teacher-prepared worksheets. It will consist of reading and memorizing some science facts related to a concept too abstract to be well-understood by the student but selected because it is "in the book."

Perhaps my task is complete with this analysis and summary of conditions for science in the elementary school. However, I would like to offer an analysis of specific problems that I feel are responsible for this sad situation.

Problems in Reaching New Focus

A series of problems continues to perplex us as we attempt to resolve the current crisis and characterize a new science for schools—a new science that provides better preparation for students who need to prepare for life in another

century. An elaboration of these problems is provided—in simple terms and with obvious correctives in mind. It seems to me that these problems and specific correctives should be a focus for this conference.

First of all is the supremacy of the textbook in K–12 science teaching. The recent NSF status studies reveal that 90 percent of all science teachers use a textbook in excess of 90 percent of the time. The textbook seems to determine content, mode of instruction, evaluation, and what students learn. The major curriculum decision that teachers make is choice of the textbook. Once determined, most teachers attempt to cover all content in the book, usually in the same order and with the instructional aids provided or suggested.

Another lingering problem is the implicit goal arising above all others that the major justification for school science is the preparation it provides for the next academic level. Teachers frequently justify their courses, the content covered, and instructional stategies adopted because "it is expected by teachers at the next level." Surely this is worst when secondary school teachers insist that college teachers expect certain coverage. The evidence suggests that the teachers at the next level rarely expect anything and, regardless of what is done at earlier levels, find fault or ignore the experience of their students.

A third problem is that the goals of science instruction are limited to certain knowledge and certain processes. Such a two-dimensional view is limiting and inaccurate. Like most complex enterprises of the human being, science is multidimensional. Some of these dimensions are far more appropriate for many learners than the process and content dimensions. Some have argued that several other dimensions are far more important for achieving general scientific literacy than are process and content; some suggest that process and content are least important of all. Surely an argument about the relative importance of process and content is simplistic and in error.

Another major limitation in moving science teaching in directions that are becoming clear is our failure to consider science *curriculum*. Brandwein suggests that we have never considered a theory of curriculum and that we have never had a science curriculum as such. We have been content to compartmentalize science as scientists do and to argue the order of presentation of the various disciplines.

A related problem is our failure to define science content in any way other than through a discipline orientation. Most discussions of science teaching quickly reduce to a consideration of relative emphasis and sequencing of given science topics—always those traditionally packaged in various discipline-bound courses. This simplistic view of science explains our failure with curriculum; it also explains our inability to consider other dimensions of science.

Another major problem has been our inability to move beyond the lecture as a form of instruction. Student recitation following a lecture or a reading assignment indicates still another problem. The emphasis is upon presenting material (content) for student mastery. The recitation becomes a form of motivation for students who want to succeed.

A seventh problem exists with the so-called laboratories that characterize school science. Some studies have revealed that most science courses do not include a single experiment where students define a problem, propose procedures, and collect and interpret results. Some insist that students rarely engage themselves in activities where the answer is not provided by the textbook authors, the teachers, or other students. Many activities in science classrooms are merely exercises in following directions and verification of information given by the text or the teacher.

School science is on the list of important priorities for schools as viewed by the public in a recent Gallup Poll. However, science appeared next to the bottom of the list of priorities; eighteen other curriculum areas and school functions were viewed as more important. Reading was at the top of the list; the public places reading as the highest priority for the school. However, second to reading is the development of reasoning; critical thinking, logical thought, and the like. It is alarming to realize that the public does not associate logical thinking with science. And it is disappointing to find that science teachers do not recognize its importance to science.

Another problem that remains is the "belief" of students that their study of science will be useful. Students enrolled in science are satisfied customers. They like the textbook, teacher lectures, the definitions, and the rest. In fact, the longer they stay in school and the more science they complete, the greater is their belief in the ultimate value of their studies. For the few winners who proceed through the system through graduate education, this may be

appropriate. For most, however, the disillusionment with the value of school science arises when they are adults at work in a variety of careers.

Evaluation of success in school science is a problem, mainly because it mirrors the emphasis upon content for its own sake, teacher lectures, and textbook presentations. Basically, students are expected to replicate what is given to them to study and do. Emphasis on definitions and the knowledge dimension tends to close science, to make puppets out of students, and to reduce science teaching to a concern for definitions, vocabulary, and laws.

It has become common to omit the human being in science courses. This occurred when all applications were removed and when the emphasis was placed upon pure science. All sensitive areas were removed or at least deemphasized. There has been no emphasis upon conflict or the persons actively engaged in scientific pursuits today. There has been an attempt to remove science from the society of which it has always been a part.

A final lingering problem is our use of the science classroom and laboratory as an exclusive setting for science. We have attempted to package courses, including laboratory activities, in a way that they neatly fit into class periods, the school day, and the school year. We have been quick to use the vast resources that the personal experience of every student might bring to class. We have failed to realize that the world itself is the real laboratory for science studies. Some now feel that most of what a student knows, thinks, and does relating to science comes from nonschool experiences. Instead of school science affecting student behavior in out-of-school settings, school science seems to have little relevance.

Attending to these lingering problems is an imperative. Surely their solution would bring a new school science—a kind of science that can be an effective force for producing the kind of world we want and must have.

Search for Exemplars

As the crisis in science education deepened, the NSTA initiated a new project designed to identify programs that characterized the new foci described previously. The Search for Excellence in Science Education (SESE) steering committee selected the criteria for the 1982 search that were established by the Project Synthesis researchers as the "desired state conditions." There was general belief that there are schools and teachers that have progressed toward such excellence—if indeed it has not been attained. On the other hand, it was assumed that such situations would be rare; otherwise these would have been noted in the extensive NSF status efforts of the late seventies.

Before closing, I would like to review the general features of the desired science teaching conditions for the K–9 grade levels developed by the Project Synthesis Elementary Science Group. First of all, a good, effective K–7 (or if we wish to extend it, K–9) science program would concentrate on effective consumer behavior. Second, a good science program would deal with effective personal health practices—medicines, etc. A third point suggests that a good science program would recognize that people affect their environments and that a custodianship with the world in which we live should be developed.

A science program also should enable students to observe variations in the interpretation of data, rather than believing there is always one "best" way for data to be interpreted. The next point states that, in a good elementary science program, students will experience the hard work required to resolve problems, and I emphasize "resolve." Some science educators now suggest that "resolving problems" is a better term than "problem solving." (Some people have made it seem that problem solving skills and logical thinking can be developed very quickly. The real problems of our time cannot be solved in one class period, or even several. Due to time constraints, one often resorts to game playing, but that does not involve work on real problems.)

An effective science program also will focus on a variety of basic sciences with science defined in its broadest sense. I like to think of science in many dimensions—certainly not just in the content dimension, which is a record of what knowledge has been reported by scientists. The seventh point I would extract from a longer list of ideal state conditions is that an effective science program in K–9 settings will recognize the *people* at all levels who are involved with scientific and technological pursuits. This point touches upon career awareness and the fact that science is something *people* do.

In the past, science courses have mirrored college courses. Such courses always respect the boundaries of discipline where concern is for the quantity of content students are likely to encounter in each discipline.

Although teachers talk of other goals—give lip

service to them—the major goal in practice is preparing students for the next course or the next academic level. Secondary school science is justified too often as college preparatory even in the elementary school. With such an emphasis—usually ignoring any other possible goal—typical graduates of a K-12 program achieve a diploma and enter adulthood scientifically illiterate: unable to use the information mastered, unaware of the basic features of science, unable to think logically, unable to make decisions about their own welfare.

New programs in science must emphasize the *use* of scientific knowledge and scientific procedures. They must focus on technology and application. They must provide experience with using information in arriving at decisions—decisions that will affect personal well-being and the future of society.

Science education of the past has not helped produce citizens for the life they will lead. It has focused entirely on preparing people for further study for careers they will not follow. Fortunately there are many encouraging signs on the horizon; fortunately there are many examples of new programs that have been designed to respond to the current situation. The ACS ChemCom is surely one example!

George Bernard Shaw shared an idea some years ago that I feel is appropriate to set the tone of our conference. He said that some people see the world as it is and lament, "why does it have to be so?" Others (often too few) see the world as it might be and ask, "why should it not be so?" We could spend much time lamenting our problems; we could spend much time debating causes, interpretations, and relative seriousness; we could, perhaps, even justify the status quo. I would hope, however, that we would instead consider the "desired state conditions," perhaps elaborate upon them; perhaps even provide alternative visions of what might be. The real task then is to develop a plan to give such visions a chance for reality. Such attempts, such experiments, such reality provide the excitement, the evidence, the experience to provide the kind of K-9 science for which we all yearn.

What To Do About Science in the Elementary School

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Science has virtually disappeared from the elementary school day. Should we worry about that? If so, what is to be done? This brief presentation provides some answers to both questions, as well as some of the background that ought to inform any action ACS may take. (The entire Spring 1983 issue of *Daedalus*,[1] the journal of the American Academy of Arts and Sciences, is devoted to the topic of scientific literacy and gives a fuller treatment of ideas mentioned below.)

Children begin creating explanations for phenomena when they are very young. If anyone will listen, they have a million questions to ask and they absorb some small part of the responses they get. Out of their experiences and answers they construct home-grown theories, ("becauses") some of which are sound, many of which are not. But right or wrong, these beliefs that develop early become firmly embedded and cannot be easily replaced. (For example, just telling them a different "story" fails usually to produce a real reorientation. As anyone who has tried to teach physics to high school students knows, what was learned early and in a natural mode is usually there to stay.) This fact of early spontaneous, and often erronous, learning argues for early intervention.

The research suggests that to develop really meaningful ideas in science and to dispose of misconceptions, the concepts and explanations must be experienced on many occasions in different contexts. In fact, it seems clear that while one can get students to learn to say almost anything one wishes, there is no evidence that such exclusively verbal learning—what I call the "Tell, Text, Test" mode of instruction—functions effectively for them in problem-solving situations. On the contrary, they need a great array of direct experiences and plenty of opportunity to talk over what went on, why that probably happened and the "so what" of it. The agenda for a full cycle of instruction appears in Figure 1. (This figure is also applicable to the high school context.)

[1]Graubard, S. R. (ed.) "Scientific Literacy: Spring 1983." *Daedalus, Journal of the American Academy of Arts and Sciences*, **1983**, *112*(2), 1-248.

Given that a sustained exposure to science should be part of the elementary program, why has it disappeared and what are the implications for any interventions ACS as an organization might make? There appear to be five reasons for its absence from the elementary school day.

First, despite its substantial contribution to language development generally, science is nevertheless a low-priority subject, knocked out by the back-to-basics movement. Apparently, the considerable accumulation of research on its effect on language and logic development, particularly for disadvantaged students, simply never got the attention it deserved.[2,3,4]

Next, the image of science as a low-priority subject is reinforced by the fact that it is not included in most of district-level program testing schedules.

Third, science has few advocates. This is where individual members of ACS could take a hand. If science is left out, nobody complains; not parents, not administrators, not teachers.

Fourth, in a busy school day it is nearly impossible to conduct science as an activity program, given the fact that it usually requires more time to assemble materials and prepare the lessons than do other subjects. Furthermore, since anything a teacher sets up is likely to attract attention before one is ready to use it, and since space is so limited in most classrooms, there is a problem about where things can be safely left until needed.

Finally, of all the subjects in the curriculum, science produces the most anxiety for elementary teachers. The reasons given relate to its effect on discipline (children get too excited in the view of some teachers, they make noise, and people will think the teachers are not running good classrooms). Administrators say teachers do not know enough science; teachers say that may be partly true—little of their college science seems practical or pertinent—but it is more a matter of time to prepare, and time in an already crowded school day for the science program. Many teachers list science in their plan books but do not actually teach it or, if they do, it is exclusively a reading program.

Given that all of the above are correct statements of conditions, and if we consider the fact that students need a great variety of brief exposures to phenomena they can discuss, what might ACS do? I think there are a number of possibilities.

First, develop a series of brief, well-illustrated booklets, possibly in a comic-book format, each of which gives some simple home science activities that children at different ages could try.

A briefing page for any adults who might be helping could be included—that is, do something that increases out-of-school attention to science.

[2]Bredderman, T. "The Effects of Activity-Based Science in Elementary Schools." In *Education for the Eighties: Science*, edited by M. B. Rowe. Washington, D.C.: National Education Association, 1982.

[3]Wellman, R. "Science: A Basic for Language and Reading Development." In *What Research Says to the Science Teacher*, edited by M. B. Rowe. Washington, D.C.: National Science Teachers Association, 1978.

[4]Rowe, M. B. "Elementary Science: A Vanishing Species." *Science and Children*, **1980**, *18*(1), 19–21.

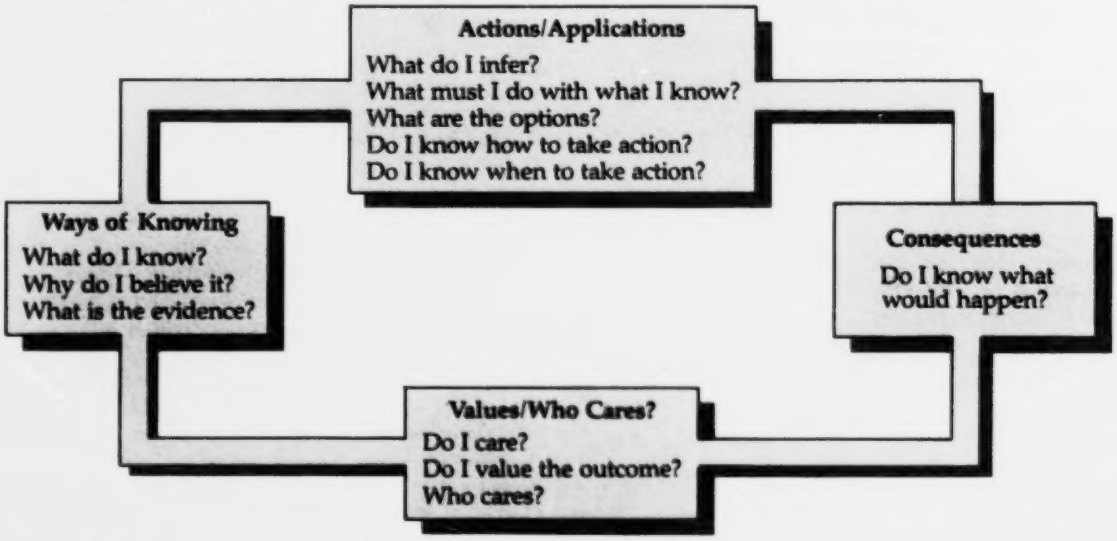
Actions/Applications
What do I infer?
What must I do with what I know?
What are the options?
Do I know how to take action?
Do I know when to take action?
Ways of Knowing
What do I know?
Why do I believe it?
What is the evidence?
Consequences
Do I know what would happen?
Values/Who Cares?
Do I care?
Do I value the outcome?
Who cares?

Figure 1. Four Components of a Full Science Program

These booklets might also include possible science-fair projects.

Next, institute an "adopt a district" program in which members of ACS in a region would provide a variety of kinds of encouragement to particular schools:

- Talk to school board members about the need for an active elementary science program.
- Hold "ask a scientist" sessions for classes at any level. Students have little or no opportunity to ask questions about science-related things.

I once was the "visiting scientist" in a rural, southern second-grade classroom where they were doing something called career education. The children had about 10 questions they had apparently been taught to ask, including "Do you have career satisfaction?" (Imagine, second graders!) It took only a few minutes to get through their list then we faced each other in silence. Finally I said, "If you had a chance to ask a scientist any question you wanted how many of you would have a question?" All the hands went up. "OK, I will try to answer as many as I can. No scientist knows everything so what I don't know I will try to find out for you." Two hours later I was still answering questions—and there was a lot of homework for me!

- Provide a series of interesting and useful information sessions for teachers with demonstrations they could use in turn with their classes. ACS might develop the basic guidelines for such sessions with examples of content.
- In each region examine the content of science texts to see which parts of Figure 1 are missing.

Usually the application, or what children call the "so what" aspect of things, is missing. This is an area where chemical engineers could be helpful in providing supplemental materials, particularly in the upper elementary grades. Right now, if science is being taught, it tends to be only the first question in the "Ways of Knowing" box of Figure 1. The NSF-funded elementary programs of the sixties tried to address some of the other questions in that box. Very little was done related to the "Actions" box, and yet research indicates that most student interest resides in that and in the right side of the cycle.

- Plan some Saturday or Sunday afternoon science programs for interested children and parents.

In this day and age, we need to start instruction in science in the early school years. We need to educate parents as well, not just that there is a problem, but that they can be part of the solution. But it makes a difference how we do it. No matter what the mode of delivering science is, the ingredients of Figure 1 must be incorporated.

There is reason for professional organizations and their educated members to take an interest in precollege education; and elementary science education in particular. What we do, or fail to do, has practical and attitudinal consequences.

"How well a nation thrives and how rapidly adaptation takes place depends in part on the extent to which a substantial portion of its people understand the connections between possession of scientific and technological knowledge and the power to act effectively on the world. The products of science and engineering indeed produce fundamental shifts in economics and world view, but the methods of science and the values attached to it have the power to shape our sense of purpose and to turn us into architects of our destinies." (From "A Framework for Decision-Makers," *Daedalus*, Vol. 112, No. 2, 1983.)

To put it bluntly, science people of all kinds need to come out of hiding, to lend a hand with helping children and their teachers. More children need to get to know some adults who find science a "pretty neat way to think about things." There are thousands of chemists of one kind or another in the country, possibly enough so that each school could have one of its own, so to speak. How about an "adopt a school program" for ACS?

Thoughts on Designing a K–9 Chemistry Curriculum

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I would like to break my talk into three parts: my own biases, questions about what ACS might conceivably do in this area, and what there is about chemistry, or physical science, or even science, that might make some impact on the elementary schools.

Biases

First of all, my biases. Two classes of people are unbiased: Dead people are unbiased. Completely ignorant people are unbiased, since they don't know anything.

By the time I arrived at this workshop, I was biased. I read some very interesting material regarding our topic! This does not make me an authority, it just makes me biased. I talked with many science education supervisors in southern California and in the Los Angeles City and County school systems. I talked with principals and teachers. I even announced to my physical chemistry class that I was going to Washington, D.C., and typically, they had invited someone to speak who doesn't know anything about the topic. As a result, I had a good discussion with students on their thoughts on elementary education. So you see, I come well-prepared. You could even say I conducted a national poll since one or two of my students are not from California!

I learned that science supervisors generally think the biggest needs are for better background preparation for teachers and more in-service education. Southern California used to have a rather rigorous in-service education program. In essence, the teachers were forced to take the program to get pay raises. Although this requirement has almost disappeared, science supervisors think there is some merit in going back in this direction.

The principals feel they can't recruit the teachers they really want because of low entry level pay. They also wish there were something they could do about summer employment. The most fascinating bit of information I learned was that principals thought the level of teaching was improving in elementary grades as was the level of science. As I tell my students, the only advantage in scoring an "F" on the first exam is that you can do nothing but improve. I was really intrigued that they thought the situation was improving. However, I didn't talk to them long enough to find out *why* they thought so.

In general, teachers feel they need more time. The most common phrase I hear with respect to that, concerning our college and university courses, is our "constant volume curriculum." (If you apply the Ideal Gas Law to the curriculum you come up with some rather interesting analogies!) Teachers felt they should be able, more than they are, to use outside experts—people who come into the classroom to help teach. But they seem convinced that such people should be acquainted with teachers and students before assisting with the lesson. Teachers don't want these experts to come and just talk from their own backgrounds.

The students with whom I spoke were at the college level, studying science. They felt strongly that there should have been more hands-on experimentation in their precollege science training. Almost none of them remembered what had occurred in elementary school. They remembered quite well what they were taught in junior high, but had a difficult time recalling what happened before the sixth grade. I think this is true of many people.

Another personal bias: I have tried for a long time to talk about learning theory with students at all levels. I think students should know about short-term memory and long-term memory. If students understood how their memories worked, they would be much more intelligent in their ways of study. The more we can tell students—at their appropriate levels—the better off they will be. I find students at the university level are resistant to learning about these theories. I am not trying to prepare students for college; I'm merely saying that if they don't learn these concepts early and work them out on their own, they may have great trouble later on.

Another of my biases is that I think it is a mistake to blame the teachers, students, or parents for the problems of the elementary schools. I think the problem lies with the colleges and universities. One of the most satisfactory aspects of our educational system is that it has roughly a 12- to 16-year cycling period. If we really worked hard on these problems, we should be able to solve them on the order of 15-to-20 years.

As a scientist, I think it is very important to study the kinetics of the situation. Kineticists learn quickly that nearly all processes have a

slow, rate-determining step. The process itself may take a long time, but usually the overall rate will be determined by a single step. I happen to think that the place we can attack best is the place at which some of us work—colleges and universities. After all, all teachers in this country have four years of tertiary experience. I would put tertiary education as the key area of focus.

Another bias: The public's setting of desired educational goals is much lower than I wish it were. The population in general may not appreciate this, but education is a subversive force. It can destroy families, societies, and governments. I am convinced that many rulers do not want good educational systems in their countries. They know that such a system could overthrow their governments.

I think the same is true in this country, but for somewhat different reasons. Most people in this country do not want the schools to teach students to think or to collect or evaluate evidence. They want the schools to teach students basic tools—reading, writing, and arithmetic. When you go beyond these three areas, you're in serious trouble with a high fraction of the population.

Science is not monolithic. One of the biggest problems people have in perceiving science and scientists is that they see in the public press that scientists do not agree with each other about social problems. Take the issue of the nuclear freeze as an example. Distinguished scientists are found on both sides of this problem. *Science* has nothing to say about a nuclear freeze—*scientists* do. I think science is in a weak position now because it is obvious to many people that scientists are indeed divided.

This point goes well beyond the idea that science is difficult to understand. A scientist is bound to lose almost any argument. Why? Think about the definition of a good scientist. If you ask, "Are you *sure* about X?" the answer will be, "I am not sure." Is the sun going to rise tomorrow? "I'm not sure. I'm positive, but I'm not sure. I can think of future times when the sun may not rise." So scientists cannot be sure, which creates a tough handicap in winning arguments.

Studies by Mandrell and others have revealed that there is only one profession in which eventual success correlates with earlier success in tertiary education. It's not medicine or law, or even football. It's tertiary education itself. Most of us in college are in the business of producing intellectual offspring. We reward students for behavior that—had we shown such behavior at their age—we would be even better off as professors than we are now.

Scientists have attributes that are not appreciated by others. One is that scientists must have a high tolerance for deferred rewards to be successful. Yet, as I understand it, rewards have to come quite rapidly at the elementary school level. I think this is a basic source of tension between teaching science the way scientists view it and what actually occurs in elementary classrooms. Most scientists are willing to work for a long time, and don't understand why others aren't willing to work just as long without receiving any tangible rewards—and usually little pay.

These aren't all my biases, but they are the ones I thought most appropriate to interpret what I will say later.

What Can Be Done?

What can ACS do in the area of elementary science education? Overwhelming evidence suggests that a lot of people are working hard in this area. The last thing they need is for ACS to launch its own program. I didn't say ACS *shouldn't* do it, I only said it's the *last* thing they should do. (I express these opinions as declarative sentences. You should interpret them as questions to be processed during the workshop.)

The *first* thing ACS should do is establish immediate contact with as many other professional societies as possible—science societies, teaching societies, education societies, foreign societies. Before you do anything else, it pays to find out what others are already doing in elementary school science.

ACS could conceivably provide assistance in three categories: money, ideas, and personnel. I don't think ACS is in the business of providing very much money. The Society can certainly provide ideas and—if not personnel—at least media and other teaching resources.

I hesitate to bring up my next point, but I think its discussion is absolutely essential. In almost every college and university, the education department is at the bottom of the academic and intellectual totem pole. Furthermore, it is well known, whether actually true or not, that students entering teacher education are the most poorly prepared. I don't know that it's true, understand, I'm just saying that it's *known*. I know a lot of things that are not true. I am suggesting that if the gulf—which is really a chasm—isn't recognized, little can occur

productively between the scientific and educational societies.

ACS also can help with laboratory equipment design. Most school equipment is over-designed. Equipment must be designed effectively to be operational. I hope the ACS can get involved in generating coordinated systems more than they have in the past. I also hope the ACS can provide more ideas for teaching with less "over-designed" equipment. I think the importance of laboratory equipment is greatly overrated. I would be willing to teach general chemistry using only equipment that is in this room right now. The major problem is what you do with what's available. The ACS might be very helpful in providing some ideas on this.

When designing written teaching materials you have to determine how much you want to do in science. Do you want to observe science? Do you want to describe it in terms of symbols? Or do you really want to describe what's going on more fundamentally? As far as I am concerned, a chemist is a person who looks at things at the molecular level. Whether it's necessary or even desirable to do this at the lower grade levels, I really don't know. I can assure you, however, that at the college and university level a lot of students have a terrible time thinking even about the tearing of a piece of paper at the molecular level. Why don't you try tearing some and then interpret it in terms of molecules?

Yesterday I heard some comments about science textbooks being bad. Unfortunately, there is nothing you can do to get around textbooks for most of the classrooms in this country. Only a tiny fraction of teachers can operate successfully without them. We should consider producing not what we think of as texts, but written or visual materials that have very little dependence on the teacher. I am concerned here with students who are potentially promising for society—they don't really need teachers, they need good materials.

The students that I am most perturbed about, in terms of what the school can do for them, are at the other end of the class. They need teachers. And you can help teachers by giving them some good materials. Regardless of how much we decry texts, and I've never seen one without mistakes (meaning that I don't agree with it), they are a necessary teaching aid.

Good materials need to be clear, but not necessarily right (that is, complete) at the lowest grade levels. The higher up in the grade levels you go, the more important it becomes to be right rather than clear. Most advanced textbooks are very, very right, but they are not clear! I think it's absolutely essential at the lower levels that clarity be emphasized without worrying too much about completeness.

One of the great problems with teaching at the tertiary level is the number of concepts students have already learned that are no longer true, if they ever were. There is much stored in their long-term memories that is difficult to root out. But that might not even be desirable. In fact, some university professors destroy students by initially convincing them that their education prior to the university level was wasted. I know chemistry professors who prefer students with no chemistry background at all because they bring in so many "bad ideas." It's a terrible thing to tell a student that he's wasted twelve years of his life and that you're the only person who has anything to offer him!

My point is one of continuity: Each grade tends to blame the problems of the students on the prior one. I think this is a profitless way to proceed. Take students from where they are, try to work with them, but don't tell them they've wasted their time up to then.

I happen to believe—and I think many of you also agree—that more important than texts and more important even than media at these levels are projects and problems.

The best single method by far at the university level to change a course and a curriculum is to design new tests. I think we waste our time trying to design better and better *texts*—we need better and better *tests* at the tertiary level. If the tests are appropriate, then the texts will adapt to prepare students. That's very seldom done.

The best set of tests that I know at the secondary level in science were produced in West Africa. They are very, very good. They meet most of the goals at that level that we have discussed. Some of the worst tests I've seen are produced in this country. They're essentially this type: "What did I say last Tuesday?" "What did the text say on page 86?" These questions are asked over and over again; the only things changing are the dates and pages. I don't think that is a very good way to do it, but it certainly encourages authors to write texts and professors to lecture!

Everything Is Chemical

I'd like to summarize the last portions of my talk by suggesting some areas we might explore. The first one is common substances. I think it's a shame that people know so very little about the

substances that surround them. I often start my college courses by asking students if they see any chemicals in the room. A lot of them have trouble finding any, but everything you see is chemical.

One of my clearest memories, probably from junior high, was the teacher bringing an ox eye to class and trying to dissect it. What I really remember about ox eyes is not that they're composed of irises, lenses, and so on, but that they're almost impossible to cut. That poor teacher struggled! Eyes are very tough. I think that it's extremely important to know that eyes are not just a collection of lenses and chemicals, but they are tough and can stand up to all sorts of abuse.

In the same way, we ought to talk about matches at the earliest possible moment. It's very dangerous to give matches out to a whole class, but they should learn about them. We should talk about the chemistry of such "non-chemical" areas as paintings, and we ought to use games to teach chemistry.

I'm also concerned about students' feelings about threats. Most students seem to believe that the present is much more threatening to them than is the past. This leads to lowering their aspirations and expectations. If enough people feel that way, then life expectations and aspirations will, indeed, be shortened. One of the best ways to make something come about is to believe that it is going to happen.

There is no question but that we know a lot more about these threats now than we used to. That doesn't mean the threats are worse. It just means that we know about them. And the first step in solving a problem is recognizing it as a problem. I'm suggesting that even at the lower grades we can begin talking about where these threats come from. The main threat, in case you didn't know, comes from the analytical chemist. Thirty or forty years ago it was very rare to detect things at a part-per-million level. Most measurements were in parts-per-thousand. Now it is easy to detect most elements at a part-per-billion; very soon we'll have a part-per-trillion. And before very long chemists will be able to detect individual atoms.

Analytical chemistry has become extremely powerful, and we know about threats now that we never recognized in the past. We used to blame all this on God. Remember "acts of God" in your insurance policy? God is no longer getting blamed for these things. It's important for students to know where these threats come from and what they mean.

This country is wasting billions and billions of dollars trying to reduce things to zero risk. Do you know how much it costs to go to zero risk? An infinite amount. We must learn that we cannot possibly achieve zero risk, especially at the level of analytical chemistry.

I was absolutely delighted to find out that in one of the elementary science programs the word "entropy" is being introduced. Entropy is one of the most powerful ideas you can get out of a science class—to *use* it, and not just to learn q(rev)/T. All of you since kindergarten have known about entropy. In fact, one of the most common things your parents said to you was "put your toys away—clean up your room." If you know about entropy and you understand this concept, you can lead a much more satisfactory life. I don't think that vocabulary as vocabulary is very important, but vocabulary like entropy that leads to powerful ideas is very important.

I also think it's important for students to understand early on the inevitability of change. It's one of the things that shocks them most. But it's absolutely inevitable. If you believe in entropy, you *know* it's inevitable. Students must be adaptable to change and ready for change. One of the biggest differences between scientists and nonscientists in academe is that scientists know that change is inevitable and they plan for it—in fact, they encourage it.

Finally, I want to point out that what we really ought to teach are insights such as the fact that human beings vary. Human beings are very different, even very bright human beings. We differ chemically, and we differ in our responses and behavior. What this leads to first of all is tolerance of, and then appreciation for, other human beings.

In conclusion, chemistry and science can make important contributions to social affairs. People don't like this. They don't like to think of themselves as chemicals. They like to think of themselves as free individuals who can do anything they want to do. Nonsense! Utter nonsense!

I've had my opportunity to speak. Now I look forward to hearing your comments this morning and later in this workshop.

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